Simulation analysis on co-site interference of vehicular digital communication system based on IM prediction method by BER

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Abstract
The co-site interference exists in kinds of communication systems, especially in digital communication systems, also is one of the biggest threats in electromagnetic compatibility (EMC) designation of the systems. Analyzing the co-site interference is an important process in achieving EMC performance of the system. Under the situation, the co-site interference simulation analysis of a vehicular digital communication system based on interference margin (IM) prediction method by bit error ratio (BER) was proposed in the paper. In the simulation analysis, some physical models of the vehicular communication system were established on SIMULINK environment, the upper limit of BER level for audio signals was defined as the IM, three different types of co-site interference was analyzed respectively, and the simulation results were obtained in the form of system interference bandwidth. From these results, the EMC performance evaluation of the vehicular communication system was predicted based on the IM prediction method. By comparing with the actual test results, the correctness of the simulation results was validated and the simulation analysis method can be used for reference by other communication systems was indicated.

Keywords vehicular digital communication system, co-site interference, EMC performance, IM

1 Introduction
Research of system-level EMC evaluation was developed on the basic of anti-interference research early, both of them had a same goal on achieving good performance of the system. The history of system-level EMC evaluation can be dated back to 1960s in the United States. Then after a rapid development period during 1970s to 1980s, the evaluation application was widely used in the aerospace industry and developed many evaluation programs. Among all the EMC evaluation programs developed in this period, two of them were the most famous: one was intrasystem analysis program (IAP) developed by the US Air Force [1]; another was Intrasytem EMC analysis program (IEMCAP) developed by McDonnell-Douglas Corporation [2]. Both of them were very professional and widely used. In the 1992, a co-site interference analysis program based on Ms-Dos system was developed by ITT Corporation [3]. Following the United States, other countries also took the research in the system-level EMC evaluation, like the Soviet Union, Germany, Britain and France. In our country, the research was started later. During 1960s to 1980s, majority of the electronic systems and devices were imported or imitated from foreign country, and the structure was very simple with little interference in them. In this period, the EMC performance of systems had become an important issue and the system-level EMC evaluation begun to attract people’s attention gradually, however the evaluation method was still a blank in our
country. In recent years, some evaluation methods were proposed by some research institutes and colleges, such as the evaluation method by coupling degree analysis based on computational electromagnetics [4] and the evaluation method by signal power analysis [5–6] based on the four-level selection model [7]. The coupling degree in the first evaluation method is directly restricted to the attenuation degree of transmitting signal, and the attenuation degree is either restricted to the transmitting signal, the layout of radio frequency (RF) devices and the polarization direction of antennas. Through the evaluation, the co-site interference of the system can be predicted by coupling degree, the method was widely used to the wireless RF devices. In the second method, the system-level EMC evaluation was based on the four-level selection model. By analyzing the signal power of the transmitting signal in the system, the co-site interference could be predicted and the EMC performance of the system could be evaluated. The second method was widely used to the analog communication systems.

In nowadays, establishing a huge complicated communication system with numbers of digital devices in a limited space is no longer an unattainable mission, which has many advantages for such systems, but can also leads to the problem of EMI even to impact the EMC performance of the whole system [8]. To vehicular communication systems, the problem is more serious. On the view of system-level EMC, analyzing the interference is good for evaluating the EMC performance and also helpful to achieving the EMC requirement. To vehicular digital communication systems, this principle is also available. Before a whole vehicular communication system is established, some traditional EMC measures should be implemented to the system, such as layout the devices with a appropriately distance, control the RF coupling degree among antennas, use filters and selectors to the RF devices, shield the devices and cables outside and so on. All of these measures are effective to reduce interference and enhance the EMC performance. However, the interference will be very hard to reduce when all the devices working simultaneously which has the risk to degrade the EMC performance of the system. Among all the interference in the systems, the most serious one is co-site interference. In nowadays, types of digital devices are existed in a vehicular digital communication system, like high frequency (HF) radios, very high frequency (VHF) radios, global positioning system (GPS)/global navigation satellite system (GLONASS) equipments, satellite communication equipments and other digital devices. When the devices start to working, the co-site interference is easy to emerge and can badly impact the EMC performance of the system. If there are more than two vehicles exist even working together, the whole vehicular communication system will become a huge complicated communication net with numerous of devices, the problem of co-site interference will become more serious [9–14]. To evaluate the EMC performance of the vehicular digital communication system, both of the methods above introduced are not suitable anymore in case of the different signal form. To the digital communication systems in transmitting the information codes, an evaluation method by BER prediction is necessary. Under the situation, a simulation analysis on co-site interference of vehicular digital communication system based on IM prediction method by BER was proposed in this paper. A kind of vehicular digital communication system was defined as research object and the physical models of the system were established on SIMULINK environment. By analyzing the BER level of the transmitted signal, the upper limit of BER level for audio signals was defined as the IM, three different types of co-site interference was analyzed respectively, and the simulation results were obtained in the form of system interference bandwidth. From these results, the EMC performance evaluation of the vehicular communication system was predicted finally. By comparing with the actual test results, the correctness of the simulation results was validated and the simulation analysis method can be used for reference by other communication systems.

The remainder of this paper is structured as follows: in Sect. 2 the co-site interference and its theory are introduced, include of the equations of co-site interference signals. Then the simulation design and conditions definition are provided in Sect. 3. Simulation results and discussions are given in Sect. 4. In the end, conclusions are given in Sect. 5.

2 Theory analysis of the co-site interference

2.1 Definition of co-site interference

The co-site interference is a big problem in achieving the EMC performance of the communication systems. As for the vehicular digital communication systems, the
problem is more serious [15–16]. A bad EMC performance can make the communication quality degraded or the communication link destroyed.

One of the most remarkable features of the vehicular digital communication system is types of communication devices exist in a limit space and work simultaneously, which makes the co-site inference is inevitable and serious [17]. In general, there are mainly three kinds of co-site interference:

1) Co-channel interference: The interference signals produced by the devices that the frequency passband is similar with each other. By mixing in the channel and demodulating in the receiver with the useful transmitted signal, the co-channel interference will be produced.

2) Adjacent-channel interference: The interference signals produced by the devices that frequency passband is close to the useful transmitting signal. By mixing in the channel and demodulating in the receiver with the useful transmitted signal, the adjacent-channel interference. Strong adjacent-channel interference can degrade the signal noise ratio (SNR), even lead to a signal blocking.

3) Nonlinear distortion: The interference signals produced by the nonlinear devices, materials and circuits, such as oscillators, mixers and amplifiers. The nonlinear distortion is mainly includes of harmonic interference, intermodulate interference and cross modulate interference. The harmonic interference is the signals produced by nonlinear devices that the harmonic components are fell into the useful signal passband. The intermodulate interference and the crossmodulate interference are the signals produced by nonlinear devices that more than two signals mixed and are fell into the useful signal passband. By mixing in the channel and demodulating in the receiver with the useful transmitted signal, the nonlinear distortion will be produced.

Since the co-channel interference can be effectively suppressed by modern technology, it is no longer the main threat in co-site interference. But with little protection measures, the adjacent-channel interference and the nonlinear distortion are still the biggest problem. Therefore, these two types of co-site interference were simulation analyzed in the paper. Sect. 2.2 and Sect. 2.3 give the theory analysis of these two types of co-site interference respectively.

2.2 Adjacent-channel interference

Assume that the input signal is:

\[ S(t) = \cos \omega_{st} t + \beta \sin \Omega t \]  

Where \( \beta \) is the frequency modulation (FM) exponential, \( \omega_{st} \) is carrier angular frequency. Making a series expand to Eq. (1), one can obtain Eq. (2) as follows:

\[ S(t) = \sum_{n=-\infty}^{\infty} J_n(\beta) \cos[(\omega_{st} + n\Omega)t] = \\
J_0(\beta) \cos(\omega_{st} t) + J_1(\beta) \cos(\omega_{st} + \Omega)t + \\
J_1(\beta) \cos(\omega_{st} - \Omega)t + J_2(\beta) \cos(\omega_{st} + 2\Omega)t + \\
J_2(\beta) \cos(\omega_{st} - 2\Omega)t + J_3(\beta) \cos(\omega_{st} + 3\Omega)t + \\
\cdots + J_n(\beta) \cos(\omega_{st} + n\Omega)t + \\
(\omega_{st} - \Omega)](\omega_{st} + n\Omega)t + \cdots \]  

From Eq. (2), it can be seen that there are numerous signal additional components exist besides the original signal. If the signal additional components fall in to the useful transmitting signal passband will produce the adjacent-channel interference.

2.3 Nonlinear distortion

Assume that the input signal is \( \tilde{s}(t), G[\tilde{s}(t)] \) is the gain characteristic parameter of amplifier, and \( \tilde{u}(t) \) is the output signal. The relationship of them is in Eq. (3):

\[ \tilde{u}(t) = \tilde{s}(t) G[\tilde{s}(t)] \]  

Applying for a power series expanding method to Eq. (3), we can get Eq. (4) as follows:

\[ G[\tilde{s}(t)] = \sum_{i=1}^{\infty} a_i \tilde{s}^{i-1}(t); \quad i = 1, 2, 3, \ldots \]  

Where \( a_i \) is the power series coefficient, defined by the characteristic parameters of nonlinear circuit. To a certain nonlinear circuit, \( |a_i| \) is inverse ratio to \( i \).

Assume that the input signal is:

\[ \tilde{s}(t) = A \cos \omega_{st} t + B \cos \omega_{st} t \]  

Take Eq. (3) into Eq. (4), one can obtain Eq. (6) as follows:

\[ \tilde{u}(t) = a_1 \tilde{s}(t) + a_2 \tilde{s}^2(t) + a_3 \tilde{s}^3(t) + \cdots = \\
a_1(A \cos \omega_{st} t + B \cos \omega_{st} t) + a_1(A \cos \omega_{st} t + B \cos \omega_{st} t)^2 + \cdots = \\
a_1(A \cos \omega_{st} t + B \cos \omega_{st} t)^2 + a_1(A \cos \omega_{st} t + B \cos \omega_{st} t)^3 + \cdots = \\
a_1(A \cos \omega_{st} t + B \cos \omega_{st} t)^2 + 2AB \cos \omega_{st} t \cos \omega_{st} t) + \\
a_1(A^2 \cos^2 \omega_{st} t + B^2 \cos^2 \omega_{st} t) + \\
2AB \cos \omega_{st} t \cos \omega_{st} t)(A \cos \omega_{st} t + B \cos \omega_{st} t) + \cdots \]  

Use the product to sum formula to Eq. (6), the additional
signal components can be obtained, Table 1 lists the main additional signal components [18].

<table>
<thead>
<tr>
<th>The signals</th>
<th>The additional component</th>
<th>The name of component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input signal</td>
<td>( A \cos \alpha t + B \cos \beta t )</td>
<td>input signal</td>
</tr>
<tr>
<td>First component</td>
<td>( a_1[A \cos \alpha t + B \cos \beta t] )</td>
<td>fundamental wave</td>
</tr>
<tr>
<td>Second component</td>
<td>( a_2(A' \cos \alpha t + B' \cos \beta t) / 2 )</td>
<td>second harmonic</td>
</tr>
<tr>
<td>Third component</td>
<td>( a_3(A' \cos \alpha t + B' \cos \beta t) / 4 )</td>
<td>third harmonic</td>
</tr>
<tr>
<td></td>
<td>( a_3(A' \cos \alpha t + B' \cos \beta t) / 4 )</td>
<td>nonlinear fundamental wave</td>
</tr>
<tr>
<td></td>
<td>( a_3(A' \cos \alpha t + B' \cos \beta t) / 4 )</td>
<td>third order inter modulation</td>
</tr>
<tr>
<td></td>
<td>( a_3(A' \cos \alpha t + B' \cos \beta t) / 4 )</td>
<td>cross modulation component</td>
</tr>
</tbody>
</table>

From Table 1, it can be seen that many signal additional components exist besides the original fundamental wave signal after a signal through the nonlinear devices. All the nonlinear signal components are determined by the magnitude parameters \( A \) and \( B \) as well. To a certain nonlinear device, \( [a_i] \) is inverse ratio to \( i \), and the strength of nonlinear distortion effect is inverse ratio to \( i \) either. In the actual situations, the strength of the even harmonic signal components is generally smaller than the odds, and the even harmonic components interference can be suppressed easily by balance circuit. Therefore, only the odd harmonic components interference is suggest to analyzing.

As for the intermodulate interference, the signals should be also satisfied the relationship in Eq. (7):
\[
|m f_1 \pm n f_2| = |f_{OR} \pm B_n|
\]

Where \( f_1 \) and \( f_2 \) both are the different transmitting frequency of the interference signals, \( f_{OR} \) is the receive frequency, \( m \) and \( n \) both are the integer.

3 Simulation design and conditions definition

3.1 Designation of simulation process

In the simulation analysis on co-site interference of vehicular digital communication system proposed in the paper, a kind of vehicular digital communication system on audio signals transmitting was defined as the simulation object. And some of the physical models were established, with upper BER level of the audio signal was defined as the IM in the simulation, three different types of the co-site interference in the vehicular digital communication system was analyzed respectively. After the simulation, the simulation results were obtained in the form of system co-site interference bandwidth. The the EMC performance of the system was evaluated based on the IM prediction method by these simulation results.

The simulation process was designed as shown in Fig. 1

![Fig. 1 Designation of simulation process](image-url)
transmitting on the condition of co-site interference, an 
EMC evaluation criterion must be defined. In the paper, 
the BER level of audio signals was defined as the IM in 
system-level EMC evaluation. The BER level is an 
important parameter in measurement the communication 
quality of signals. The lower the BER level is, the better 
the communication quality of the communication system. 
As for system level EMC evaluation, the lower the BER 
level of audio signal is, the better the EMC performance of 
the system.

In the actual situation, the suggested BER level of audio 
signals discriminately is $10^{-3} \sim 10^{-6}$. And the upper limit 
BER level of audio signals should be $10^{-3}$ for 
discriminating most, if the BER level is lower than $10^{-6}$ 
will the audio signals be discriminated easily. Table 2 lists 
the BER levels for different types of signals.

<table>
<thead>
<tr>
<th>Signal type</th>
<th>BER level</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio signal</td>
<td>Can be distinguished mostly: $P_e \leq 10^{-7}$</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>Image signal</td>
<td>Can be distinguished mostly: $P_e \leq 10^{-3}$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Video signal</td>
<td>Can be distinguished mostly: $P_e \leq 10^{-4}$</td>
<td>$10^{-4}$</td>
</tr>
</tbody>
</table>

For the vehicular digital communication system models 
in the paper, the BER level $10^{-3}$ is enough. Therefore, the 
IM was defined as the BER level of audio signals by $10^{-3}$.

3.3 Establishment of simulation models

On the simulation environment in SIMULINK, some 
multi-channel digital communication system simulation 
models were established for analyzing different types of 
co-site interference. Fig. 2 shows the block diagram of 
the simulation physical models of the vehicular digital 
communication system.

3.4 Definition of simulation conditions

On the view of system-level EMC evaluation, the 
evaluation standard is in three levels by the system can 
achieve the EMC performance, the system cannot achieve 
the EMC performance or the system is at a critical level of 
EMC performance. All of these conditions depended on 
the definition of IM [19–20].

In the IM prediction method, the IM evaluation standard 
was defined as: When the system can achieve EMC 
performance defines IM<0; when the system cannot 
achieve EMC performance defines IM>0; when the system 
is at a critical level of EMC performance defines IM=0. In 
the paper, the simulation conditions based on IM 
prediction method was defined as follows:

1) When BER level of audio signal $P_e < 1 \times 10^{-3}$ , 
defines IM<0 and considers that the co-site interference 
signal doesn’t fall into the useful audio signal passband 
and the system can achieve EMC performance.

2) When BER level of audio signal $P_e > 1 \times 10^{-3}$ ,
defines IM>0 and considers that the co-site interference signal fall into the useful audio signal passband and the system cannot achieve EMC performance. The bandwidth of useful signal be interfered is defined as the co-site interference bandwidth \( \Delta_f \).

3) When BER level of audio signal \( P_e = 1 \times 10^{-3} \), defines IM=0 and considers that the co-site interference signal fall into the useful audio signal passband and the system is at a critical level of EMC performance. Take the co-site interference bandwidth \( \Delta_f \) as the critical level of interference bandwidth \( \Delta_f_{\text{max}} \).

4) Define the BER level of audio signals between \( P_e = 9 \times 10^{-3} \) to \( P_e = 10^{-3} \) as the critical BER level, subtract the co-site interference bandwidth \( \Delta_f' \) (when BER level is \( P_e = 1 \times 10^{-3} \)) to the co-site interference bandwidth \( \Delta_f'' \) (when BER level is \( P_e = 9 \times 10^{-3} \)), then take the subtraction result the bandwidth \( \Delta_f_{\text{IM}} = |\Delta_f' - \Delta_f''| \) as the critical co-site interference bandwidth.

5) Take the critical level of interference bandwidth \( \Delta_f_{\text{max}} \) plus to the critical co-site interference bandwidth \( \Delta_f_{\text{IM}} \), then gets \( \Delta_f = \Delta_f_{\text{max}} + \Delta_f_{\text{IM}} \) defined as the final simulation result named the system co-site interference bandwidth. Therefore the EMC performance of the system can be evaluated as: the audio signal is not interfered and the system can achieve the EMC performance beyond the bandwidth \( \Delta_f \); the audio signal is interfered and the system cannot achieve the EMC performance in the bandwidth \( \Delta_f \); the audio signal is at a critical level of being interfered and the system is at a critical level of EMC performance at the limit frequency point the bandwidth \( \Delta_f \).

4 Simulation and analysis

4.1 Adjacent-channel interference

As the simulation model diagram shown in Fig. 2(a), a three-channel vehicular digital communication system model was established for adjacent-channel interference simulation analysis, as shown in Fig. 3. In the model, the receive frequency of audio signal was set at 50 MHz, the frequency of the interference transmit signal was set at 55 MHz, both of the signals was close to each other at the working frequency. After a 30 dB attenuation in the channel, the interference transmit signal was mixed with the useful signal and fell into the receive passband then produced the adjacent-channel interference.

Run the simulation model and calculated the BER level of the audio signal, then the system co-site interference bandwidth was obtained and a ‘BER-Frequency’ figure was draw by the simulation results. From the figure, the adjacent-channel interference bandwidth was shown and the EMC performance of the model could be evaluated.
from the bandwidth. On the purpose of compare the EMC performance of system with different adjacent-channel interference, the channel coding mode of the interference transmit signal was set into six different types, and the BER level on each of the models was calculated respectively. Table 3 lists the simulation results on different channel coding modes of the interference transmit signal, while the audio signal was in binary phase shift keying (BPSK) modulation and BCH channel coding mode.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>The simulation results on adjacent-channel interference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Coding mode of the interference signal</td>
<td>$\Delta f_{\text{max}}$/MHz</td>
</tr>
<tr>
<td>BCH</td>
<td>4.40</td>
</tr>
<tr>
<td>convolution</td>
<td>7.20</td>
</tr>
<tr>
<td>cyclic</td>
<td>4.45</td>
</tr>
<tr>
<td>hamming</td>
<td>4.20</td>
</tr>
<tr>
<td>linear</td>
<td>3.15</td>
</tr>
<tr>
<td>RS</td>
<td>6.35</td>
</tr>
</tbody>
</table>

According to Table 3, it can be seen that the system co-site interference bandwidth $\Delta f$ was between 3.2 MHz to 7.4 MHz by different channel coding mode of the interference transmit signal under the condition of the adjacent-channel interference existed. The minimal bandwidth was 3.2 MHz by linear channel coding mode of the interference signal, and the maximal bandwidth was 7.4 MHz by convolution channel coding mode of the interference signal. From the simulation results, the EMC performance was evaluated that the system achieved the EMC performance beyond the bandwidth, but didn’t achieve the EMC performance in the bandwidth, and was at a critical EMC performance level at the limit frequency point of the bandwidth Fig. 4 shows the simulation result of the ‘BER-Frequency’ figure in one model, by the condition of BPSK modulation mode and BCH channel coding mode in audio signal, meanwhile BPSK modulation mode and cyclic channel coding mode in interference signal.

4.2 Harmonic interference

As the simulation model diagram shown in Fig. 2(a), a three-channel vehicular digital communication system model was established for harmonic interference simulation analysis, as shown in Fig. 5. When established the model, a nonlinear part was set into the interference transmitter, made it could transmit a third harmonic interference signal or a fifth harmonic interference signal with its fundamental wave frequency was set at 11 MHz. By setting the frequency of audio signal at 30 MHz or 50 MHz, the interference transmit signal was mixed with the useful signal and fell into the receive passband after a 30 dB attenuation in the channel then produced the harmonic interference.
Run the simulation model and calculated the BER level of the audio signal, then the system co-site interference bandwidth was obtained and a ‘BER-Frequency’ figure was draw by the simulation results. From the figure, the harmonic interference bandwidth was shown and the EMC performance of the model could be evaluated from the bandwidth, including the third harmonic interference and the fifth harmonic interference. On the purpose of compare the EMC performance of system with different harmonic interference, the channel coding mode of the interference transmit signal was set into six different types, and the BER level on each of the models was calculated respectively. Table 4 lists the simulation results on different channel coding modes of the interference transmit signal, while the audio signal was in quadrature phase shiftkeying (QPSK) modulation and cyclic channel coding mode.

### Table 4 The simulation results on harmonic interference

<table>
<thead>
<tr>
<th>Channel coding mode of the interference signal</th>
<th>Harmonic component</th>
<th>$\Delta f_{\text{max}}$/MHz</th>
<th>$\Delta F$/MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCH</td>
<td>Third harmonics</td>
<td>2.80</td>
<td>3.60</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>2.33</td>
<td>2.35</td>
</tr>
<tr>
<td>convolution</td>
<td>Third harmonics</td>
<td>6.18</td>
<td>6.30</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>5.32</td>
<td>5.40</td>
</tr>
<tr>
<td>cyclic</td>
<td>Third harmonics</td>
<td>3.20</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>2.60</td>
<td>3.80</td>
</tr>
<tr>
<td>hamming</td>
<td>Third harmonics</td>
<td>2.75</td>
<td>2.90</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>2.20</td>
<td>2.30</td>
</tr>
<tr>
<td>linear</td>
<td>Third harmonics</td>
<td>1.15</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>1.10</td>
<td>1.20</td>
</tr>
<tr>
<td>RS</td>
<td>Third harmonics</td>
<td>5.45</td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>Fifth harmonics</td>
<td>4.60</td>
<td>4.80</td>
</tr>
</tbody>
</table>

According to Table 4, it can be seen that the system co-site interference bandwidth $\Delta F$ was between 1.2 MHz to 6.3 MHz by different channel coding mode of the interference transmit signal under the condition of the harmonic interference existed. From the simulation results, the EMC performance was evaluated that the system...
achieved the EMC performance beyond the bandwidth, but didn't achieve the EMC performance in the bandwidth, and was at a critical EMC performance level at the lower limit frequency point or the upper limit frequency point of the bandwidth. Fig. 6 shows the simulation result of the ‘BER-Frequency’ figure in one model, by the condition of QPSK modulation mode and cyclic channel coding mode in audio signal, meanwhile QPSK modulation mode and linear channel coding mode in interference signal.

4.3 Intermodulate interference

As the simulation model diagram shown in Fig. 2(b), a four-channel vehicular digital communication system model was established for intermodulate interference simulation analysis, as shown in Fig. 7.

When established the model, the frequency of the audio signal was set at 50 MHz, two different interference transmit signals were set at HF frequency and VHF frequency respectively, after a 30 dB attenuation of each interference signal and mixed in the channel, the mixed interference signal fell into the receive passband of the useful audio signal and produced the intermodulate interference.

Run the simulation model and calculated the BER level, then the system co-site interference bandwidth was obtained and a ‘BER-Frequency’ figure was draw by the simulation results. From the figure, the inter modulation interference bandwidth was shown and the EMC performance of the model could be evaluated. On the
purpose of compare the EMC performance of system with different inter modulation interference best, the channel coding mode of the interference transmit signal was set into six different types, and the BER level on each of the models was calculated respectively. Table 5 lists the simulation results on different channel coding modes of the interference transmit signal, while the audio signal was in BPSK modulation and RS channel coding mode.

Table 5  The simulation results on inter modulate interference

<table>
<thead>
<tr>
<th>Channel coding mode for the interference transmitter</th>
<th>$\Delta f_{\text{avg}}$/MHz</th>
<th>$\Delta F$/MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCH</td>
<td>5.64</td>
<td>5.78</td>
</tr>
<tr>
<td>convolution</td>
<td>6.53</td>
<td>6.60</td>
</tr>
<tr>
<td>cyclic</td>
<td>5.90</td>
<td>6.10</td>
</tr>
<tr>
<td>hamming</td>
<td>5.68</td>
<td>5.85</td>
</tr>
<tr>
<td>linear</td>
<td>5.28</td>
<td>5.36</td>
</tr>
<tr>
<td>RS</td>
<td>6.20</td>
<td>6.22</td>
</tr>
<tr>
<td>Transmitter 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCH</td>
<td>7.59</td>
<td>7.42</td>
</tr>
<tr>
<td>convolution</td>
<td>8.05</td>
<td>8.20</td>
</tr>
<tr>
<td>cyclic</td>
<td>7.60</td>
<td>7.70</td>
</tr>
<tr>
<td>hamming</td>
<td>7.32</td>
<td>7.40</td>
</tr>
<tr>
<td>linear</td>
<td>7.10</td>
<td>7.20</td>
</tr>
<tr>
<td>RS</td>
<td>7.90</td>
<td>8.00</td>
</tr>
</tbody>
</table>

According to Table 5, it can be seen that the system co-site interference bandwidth $\Delta F$ was between 3.8 MHz to 8.2 MHz by different channel coding mode of the interference transmit signal under the condition of the intermodulate interference existed. From the simulation results, the EMC performance was evaluated that the system achieved the EMC performance beyond the bandwidth, but didn’t achieve the EMC performance in the bandwidth, and was at a critical EMC performance level at the lower limit frequency point or the upper limit frequency point of the bandwidth Fig. 8 shows the simulation result of the ‘BER-Frequency’ figure in one model, by the condition of BPSK modulation mode and RS channel coding mode in audio signal, meanwhile BPSK modulation mode and cyclic channel coding mode in interference signal.

![Fig. 8 Simulation interference bandwidth on inter modulate interference](image)

5 Conclusions

In nowadays, the co-site interference is one of the biggest problem in the vehicular digital communication systems. In this paper, the co-site interference of a vehicular digital communication system was analyzed and the EMC performance of the system was evaluated based on the IM prediction method by BER. In the simulation, some physical models of the vehicular digital communication system were established on SIMULINK environment, with the upper limit of BER level for audio signals was defined as the IM, three different types of co-site interference was analyzed respectively. From the simulation analysis, the system interference bandwidth was obtained as the simulation analysis results on these three different conditions of co-site interference. From the results, the EMC performance of the system was evaluated successfully based on the IM prediction method. By comparing with the actual test results, the correctness of the simulation results was validated.

In this paper, the communication system of the simulation models only involved the ordinary fixed-frequency communication system, didn’t consider the spread spectrum communication system or the frequency hopping communication system, which the latter ones are more complicated in the system structure and configuration and must make more research in co-site interference analysis. The co-site interference simulation analysis on these two types of communication systems will
be analyzed in the near future.

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References

10. Ning J. The electro-magnetic compatibility of several sets of the transceivers equipped in the same vehicle in the co-site mode. Master Thesis. Xi’an, China: Xidian University, 2006 (in Chinese)

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